Modeling Total Ionizing Dose Effects in Isolation Oxides

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High Energy Electrons in Space

Trapped Electrons E > 1 MeV

→Earth's Magnetic Field

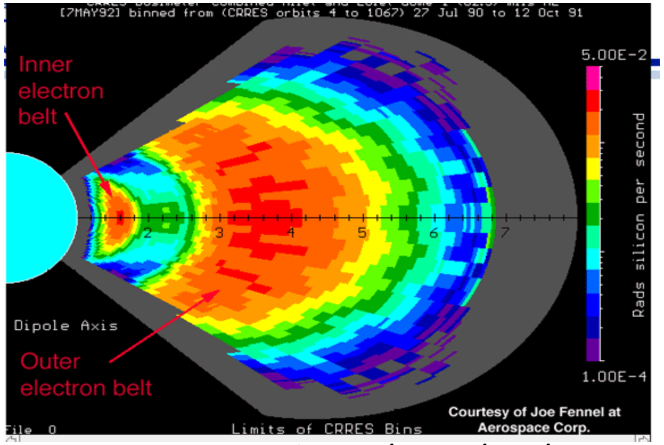
→Toroidal Belts, SAA

→Low Dose Rate

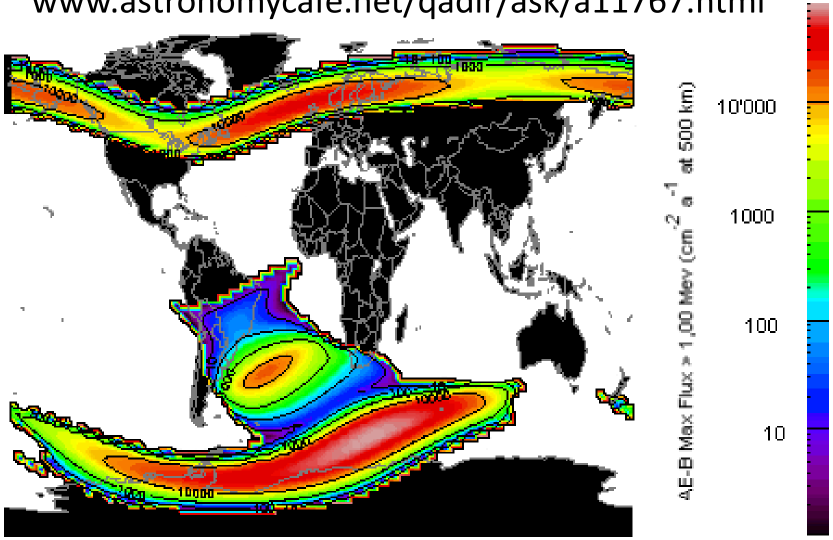
Measurement and Theory

→Total dose as measured by CRRES satellite

→Latest NASA model, AE8



www.astronomycafe.net/qadir/ask/a11767.html



www.geschichteinchronologie.ch/atmosphaerenfahrt/10-01_three-Van-Allen-radiation-belts-NASA-ENGL.html

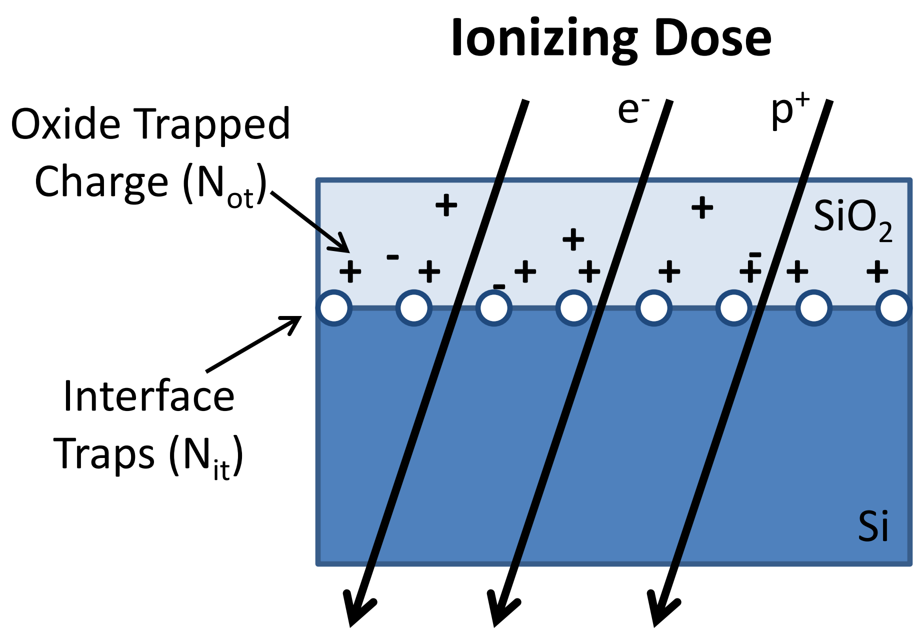
TID Oxide Charging

Dependent on

- →Hydrogen
- →Dose Rate
- →Defect Location (deposited vs grown)

Method

- →Same type of interactions in other materials
- →SiO_2 wide-band-gap semiconductor
- →Apply to SiN, AlGaN, GaN, also wide band gap

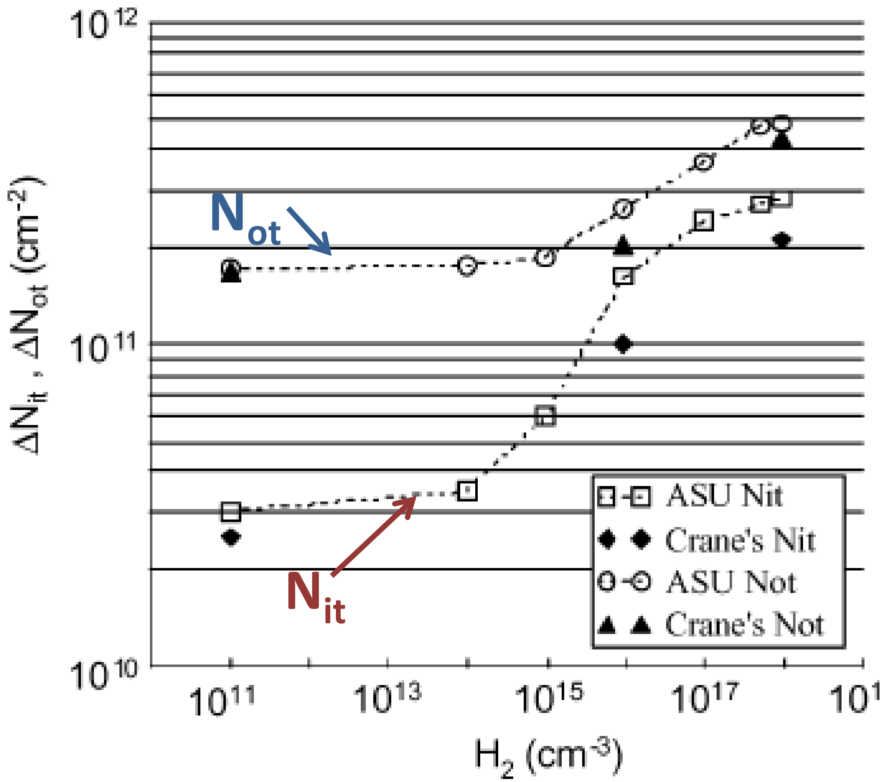


After R. Ecoffet, *IEEE NSREC'11 Short Course*, Las Vegas, NV, 2011.

Effect of H_2 on N_{it} and N_{ot}

- N_{it} increase with H_2
- N_{ot} increase with H_2

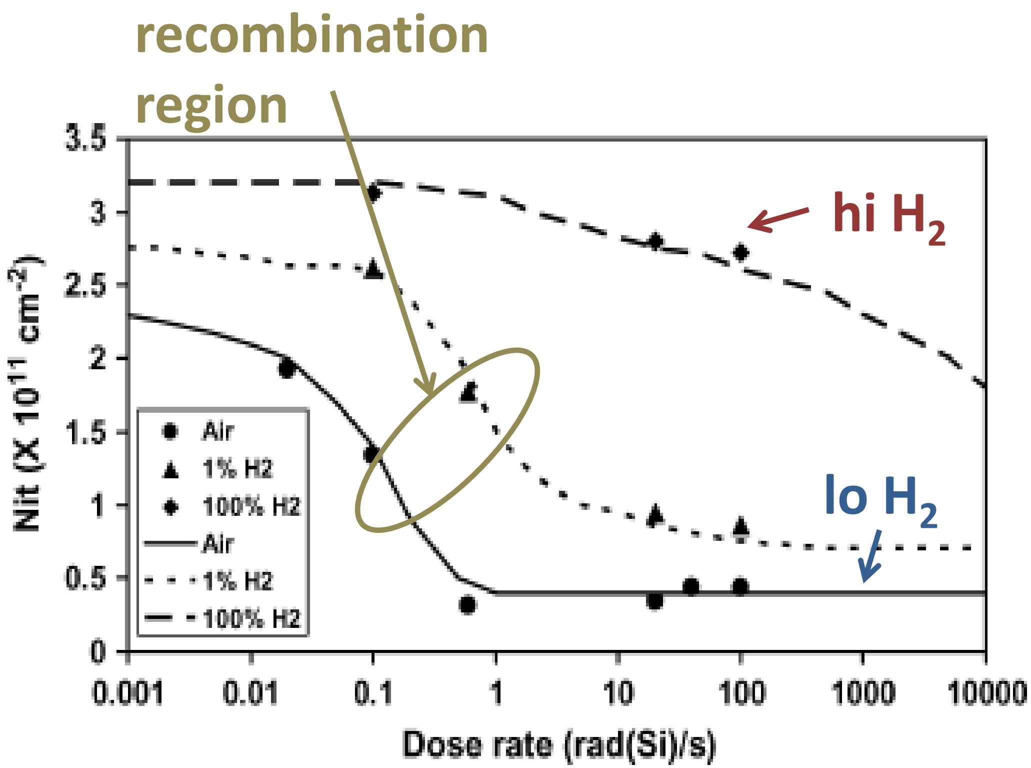
- high dose rate measurement only (20 rad/s)
- no quantitative model



X. J. Chen, et al., *IEEE Trans. Nucl. Sci.*, Dec. 2007

"lines drawn to guide the eye"

Dose-Rate Effects for Different H_2



R. Pease, et al., *IEEE Trans. Nucl. Sci.,* Dec. 2008.

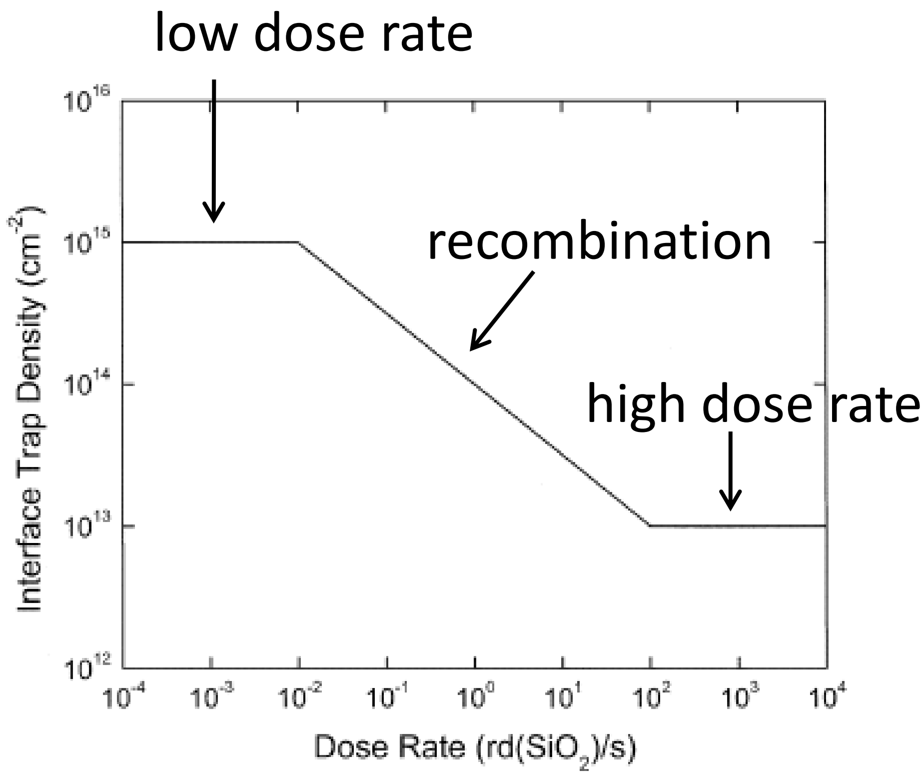
"lines drawn to guide the eye"

- High H_2 → no ELDRS
- Medium and low H_2 → more ELDRS

- no N_{ot} data
- no quantitative model

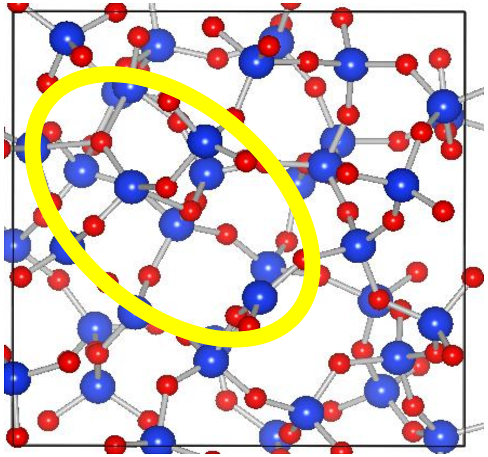
ELDRS – Theory

- At higher dose rates
  - E-field confinement
  - More recombination
  - Less N_{it} and N_{ot}
- Hand calculation
- Does not explain H_2

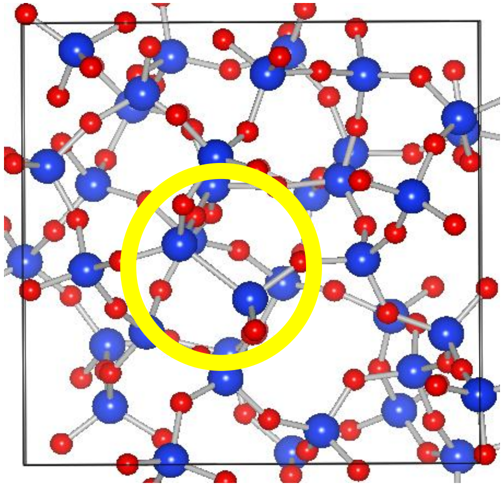


H. Hjalmarson, et. al, *IEEE Trans. Nucl. Sci.,* Dec. 2003.

Defects Analysis: DFT and ESR

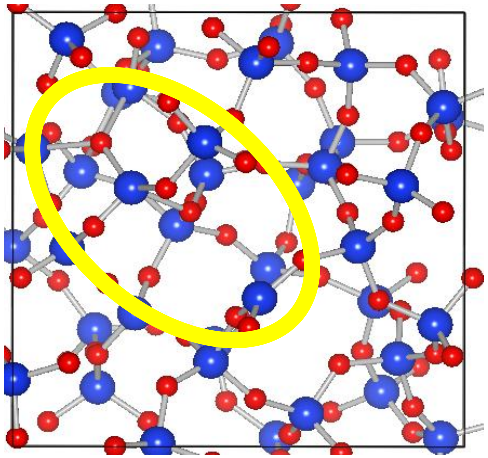


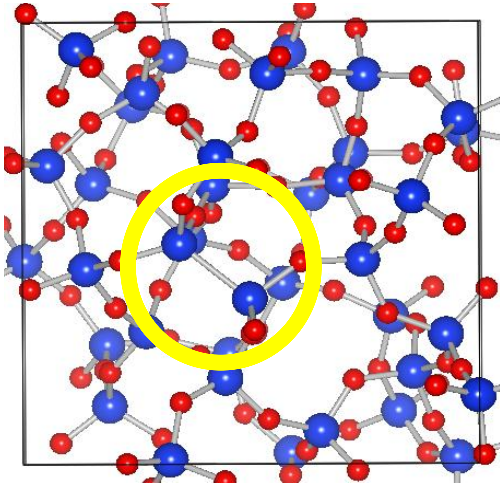
$V_{o\gamma}$



$V_{o\delta}$

Hydrogenated Defects





$V_{o\gamma}$, $V_{o\gamma}H$, $V_{o\gamma}H_2$

$V_{o\delta}$, $V_{o\delta}H$, $V_{o\delta}H_2$

Oxide Charge

Hole Capture

$V_{o\gamma}^{+}$, $V_{o\gamma}H^{+}$, $V_{o\gamma}H_2^{+}$

$V_{o\delta}^{+}$, $V_{o\delta}H^{+}$, $V_{o\delta}H_2^{+}$

First Mechanism: H_2 Cracking Reaction

Hole Capture

↓

H_2 Cracking

$$V_{o\gamma}^{+} + H_2 \rightarrow V_{o\gamma}H + H^{+}$$

"deep"

- Energy barriers from DFT calculations

2nd Mechanism: Direct H^+ Release

Hole Capture

↓

Direct H^+ Release

$V_{o\gamma}H^+$, $V_{o\gamma}H_2^+$

"shallow"

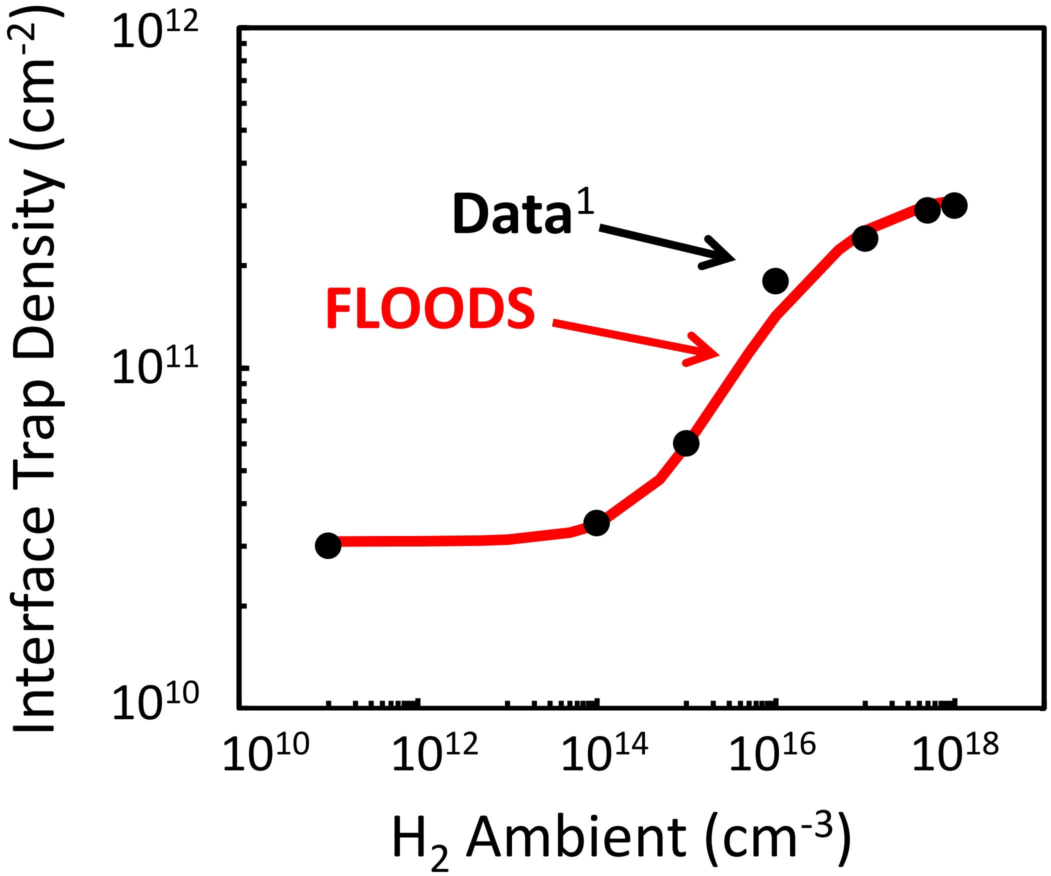
$V_{o\delta}H^+$, $V_{o\delta}H_2^+$

- Energy barriers from DFT calculations

Defects Summary

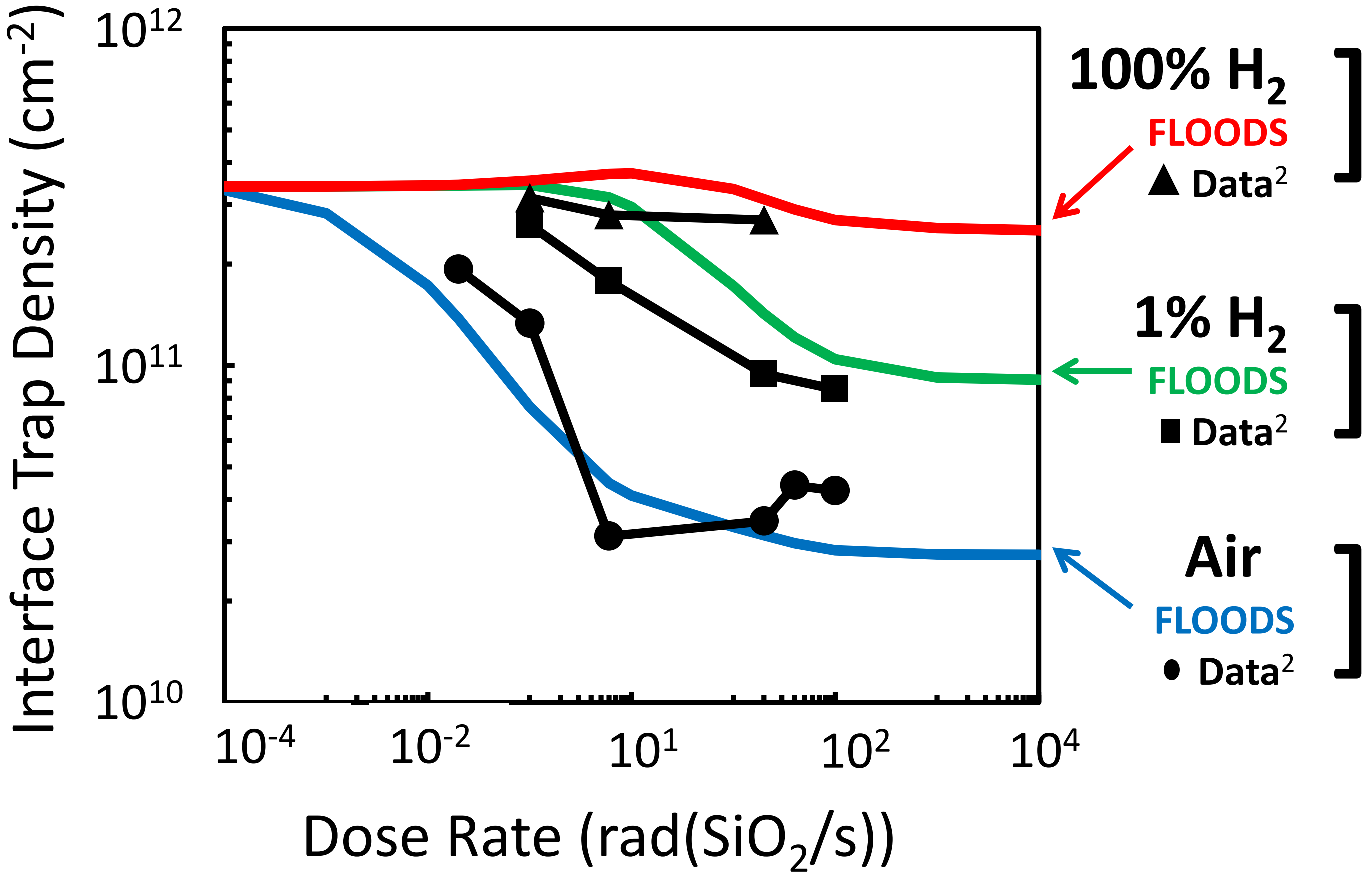
- Main Mechanisms
  - High H_2 → H_2 Cracking
  - Low H_2 → Direct release
  - ELDRS Effect → e-recomb on V^+ defects
- FLOODS Implementation
  - Drift-Diffusion TCAD, individual transient simulations matching experimental conditions
  - Add Recombination / Generation terms to account for chemical reactions, derived from energy balance

Results: Hydrogen



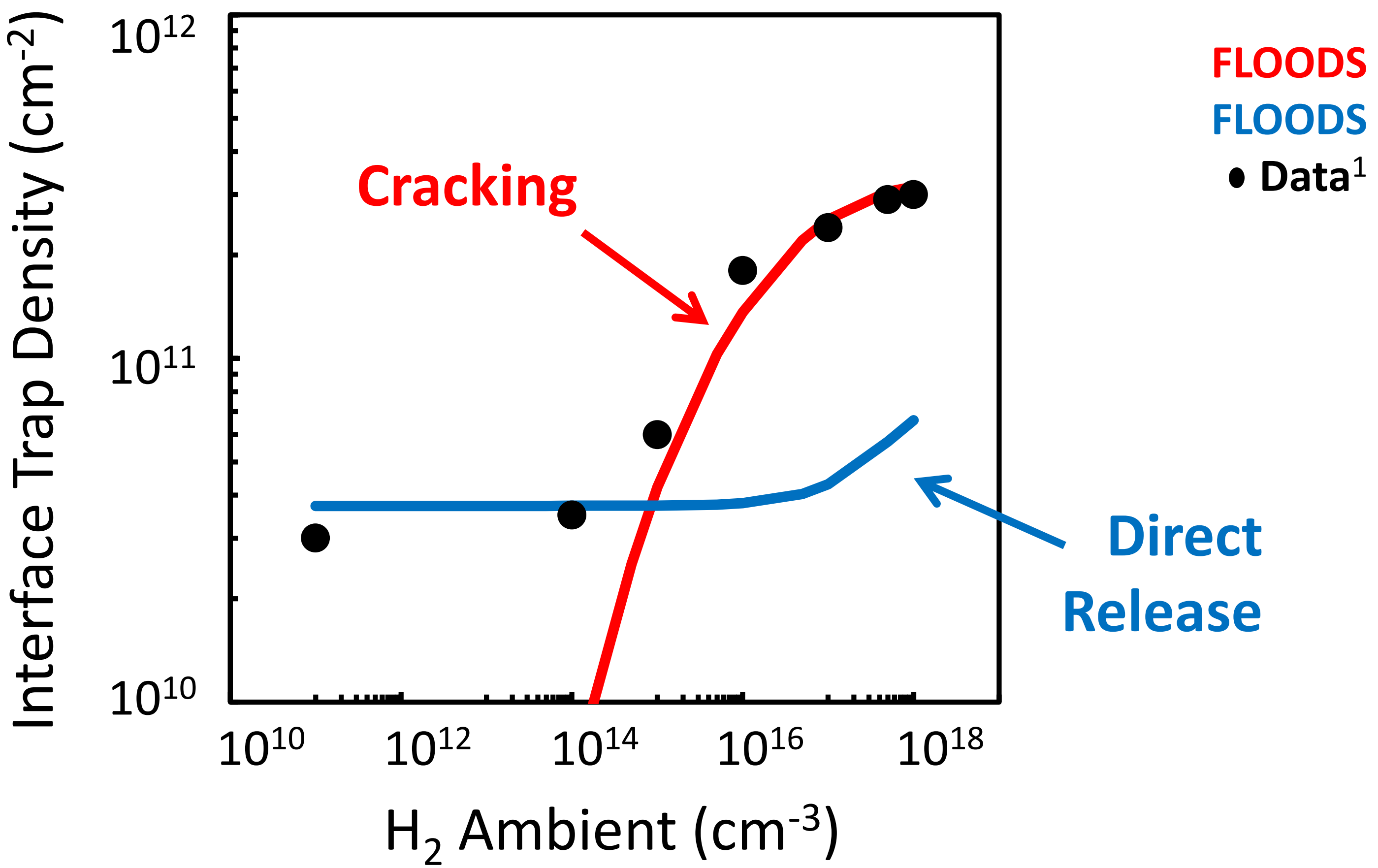
[1]Data from X. J. Chen et al., *IEEE Trans. Nucl. Sci.*, Dec. 2007.

Results: ELDRS and H_2



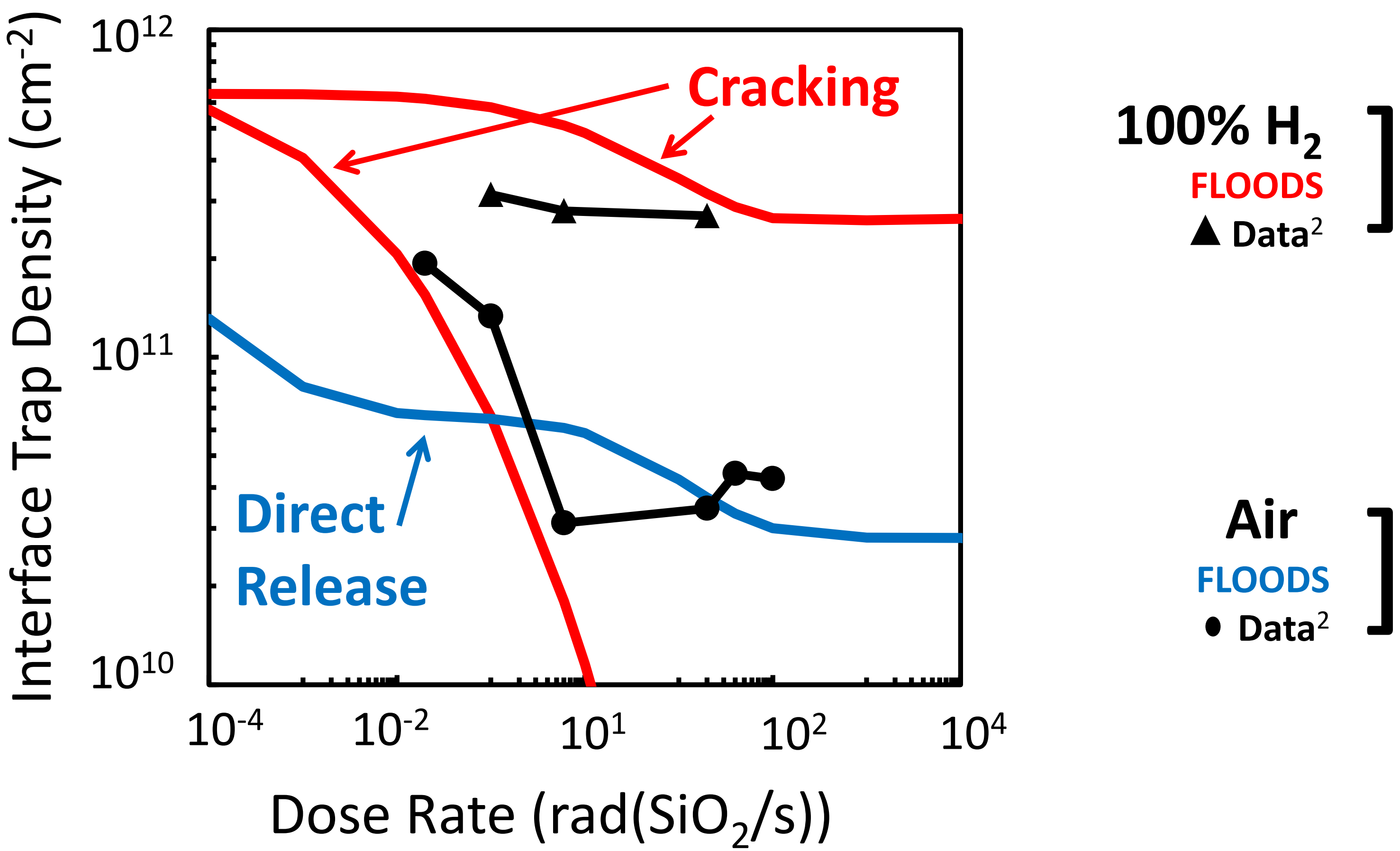
[2]Data from R. Pease, et al., *IEEE Trans. Nucl. Sci.,* Dec. 2008.

Breakdown of Mechanisms: H_2



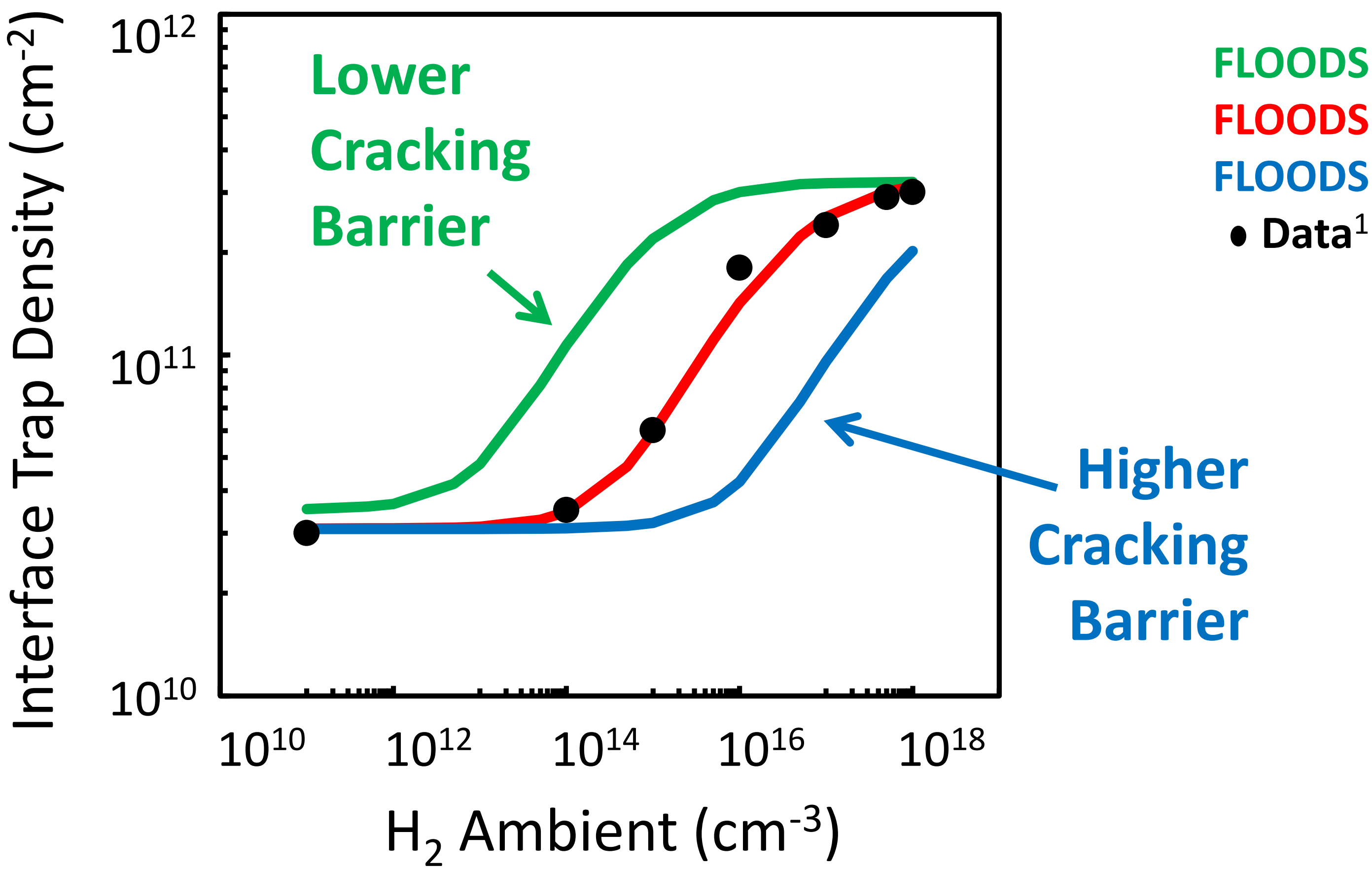
[1]Data from X. J. Chen et al., *IEEE Trans. Nucl. Sci.*, Dec. 2007.

Breakdown of Mechanisms: ELDRS



[2]Data from R. Pease, et al., *IEEE Trans. Nucl. Sci.*, Dec. 2008.

Sensitivity Analysis



[1]Data from X. J. Chen et al., *IEEE Trans. Nucl. Sci.*, Dec. 2007.

- Summary
  - Physics-based approach informed by first principles results accurately models the dose rate effects seen in different H_2 environments
- Conclusions
  - High H_2 ⇔ cracking mechanism
  - Low dose rates ⇔ cracking mechanism
  - Sensitivity analysis in FLOODS combined with first principles calculations can identify key defects and mechanisms

References

[1] R. Ecoffet, "On-Orbit Anomalies: Investigations and Root Cause Determination," Space Radiation Environments and Their Effects on Devices and Systems: Back to Basics, *IEEE NSREC'11 Short Course*, Las Vegas, NV, 2011.

[2] Chen, Barnaby, Pease, Adell "Behavior of Radiation-Induced Defects in Bipolar Oxides During Irradiation and Annealing in Hydrogen-Rich and -Depleted Ambients" *International Reliability Physics Symposium*, Phoenix 2008.

[3] Dennis R. Ball, R. D. Schrimpf, and H. J. Barnaby, "Separation of Ionization and Displacement Damage Using Gate-Controlled Lateral PNP Bipolar Transistors," *IEEE Trans. Nucl. Sci.*, Vol. 49, No. 6, Dec. 2002.

[4] X. J. Chen, H. J. Barnaby, B. Vermeire, K. Holbert, D. Wright, R. L. Pease, G. Dunham, D. G. Platteter, J. Seiler, S. McClure, and P. Adell, "Mechanisms of enhanced radiation-induced degradation due to excess molecular hydrogen in bipolar oxides," *IEEE Trans. Nucl. Sci.*, vol. 54, no. 6, pp. 1913–1919, Dec. 2007

[5] R. Pease, P. Adell, B. Rax, X. J. Chen, H. Barnaby, K. Holbert, and H. Hjalmarson, "The effects of hydrogen on the enhanced low dose rate sensitivity (eldrs) of bipolar linear circuits," *IEEE Trans. Nucl. Sci.,* vol. 55, no. 6, pp. 3169–3173, Dec. 2008.

[6] H. Hjalmarson, R. Pease, S. Witczak, M. Shaneyfelt, J. Schwank, A. Edwards, C. Hembree, and T. Mattsson, "Mechanisms for radiation dose-rate sensitivity of bipolar transistors," *IEEE Trans. Nucl. Sci.,* vol. 50, no. 6, pp. 1901-1909, Dec. 2003.